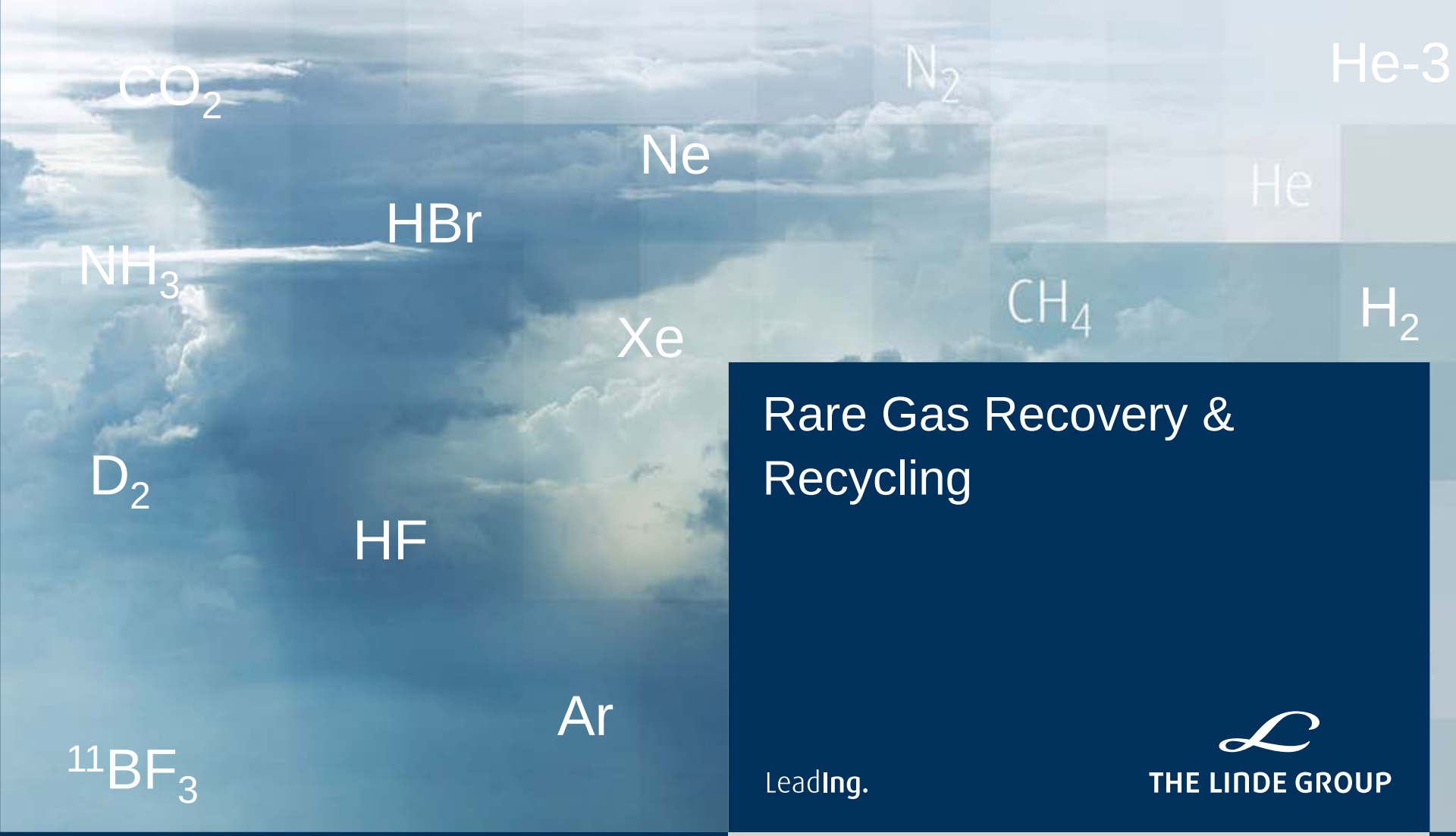


Rare Gas Recovery & Recycling

LeadIng.

THE LINDE GROUP

CMC Conference
April 26, 2018

Overview

There are a number of applications where Rare Gases (Xe, Kr, Ne) are used, but not consumed.

Rare gas recovery offers the potential for reduced costs and increased security of supply.

Presentation Overview

THE LINDE GROUP

Rare Gas Applications

Rare Gas Production

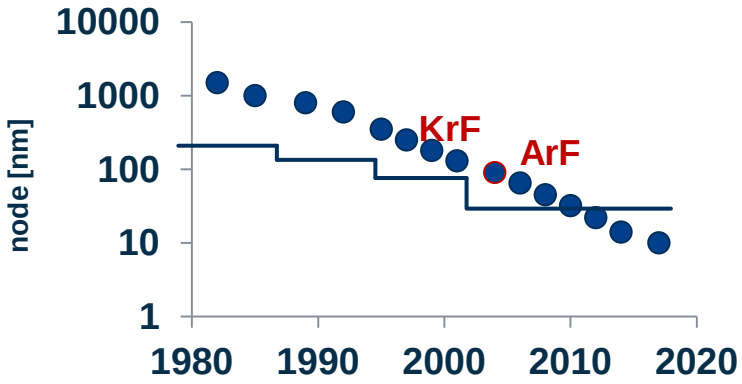
Recovery

Purification

THE LINDE GROUP

248 & 193nm UV lithography

neon and small quantities of krypton



Excimer Lasers

UV emission from Rare Gas – Halide Dimers

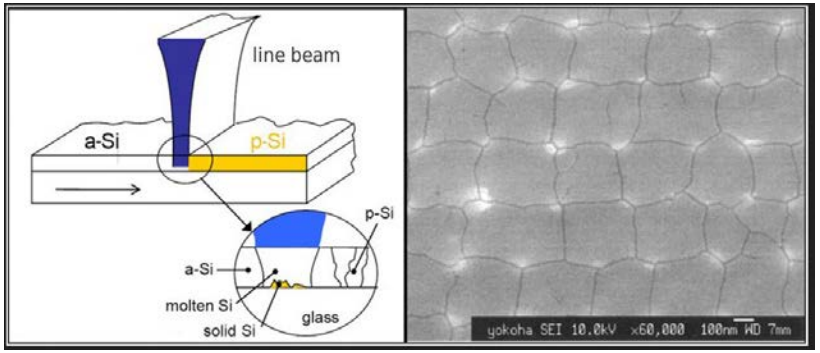
- **KrF (Kr, F2, balance Ne): 248 nm**
- **ArF (Ar, F2,balance Ne): 193 nm**

Rare Gas Applications

THE LINDE GROUP

Flat panel annealing

neon and xenon



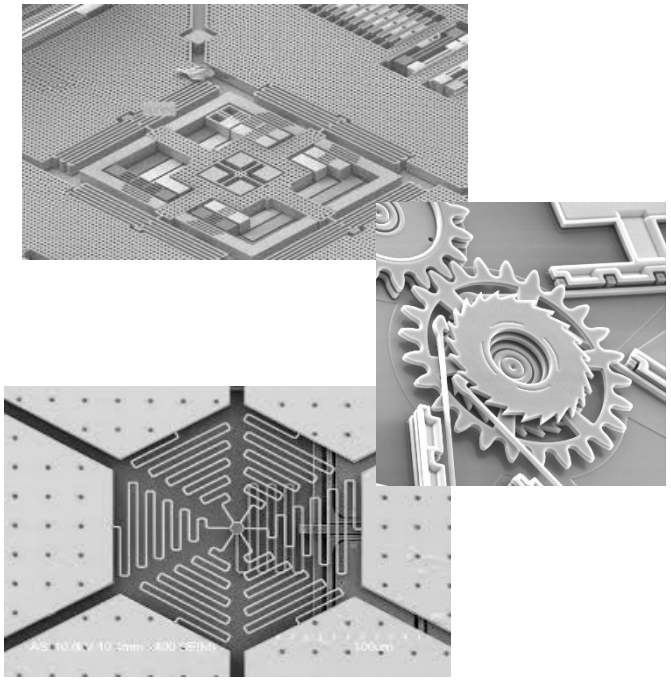
http://spie.org/newsroom/4030-power-scaling-of-excimer-lasers-drives-display-and-lidar-applications?SSO=1

Rare Gas Applications

THE LINDE GROUP

Ion etch

krypton and xenon

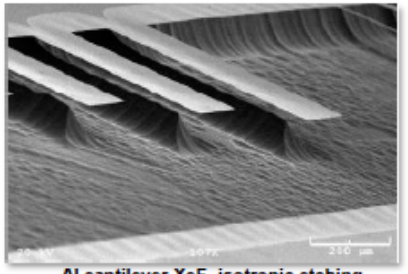


Rare Gas Applications

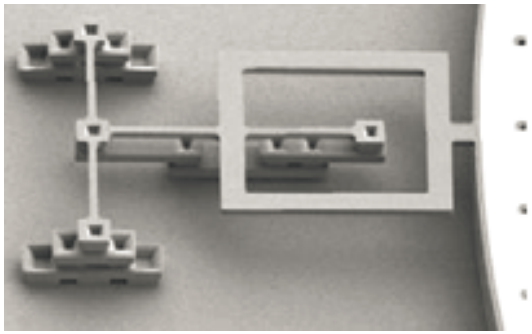
THE LINDE GROUP

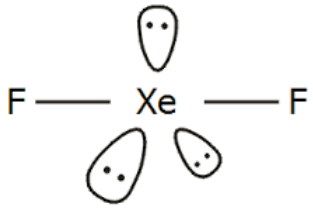
Dry etch

xenon difluoride



Al cantilever XeF_2 isotropic etching





Rare Gas Production

THE LINDE GROUP

Composition of Atmospheric Air (Volume %)

It begins with the air…

N_2	78.06
O_2	20.95
Ar	0.93
CO_2	0.033
Ne	**0.0018**
He	0.000524
CH_4	0.0002
Kr	**0.00011**
H_2	0.00005
N_2O	0.00005
Xe	**0.0000087**
O_3	0.000007
H_2O	1.57 (@ 50% RH & 25° C)

Rare Gas Production

It begins with the air… Gases are obtained through air separation.

Linde ASU Kazincbarcika, Hungary

Rare Gas Production

THE LINDE GROUP

Neon Process Flow

Large Air Separation Unit (ASU)

with neon column

Air intake > 150,000 m^3/h or

oxygen capacity > 30,000 m3/h

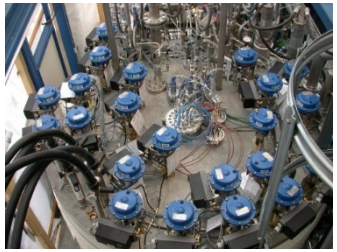
Crude Ne

50% Neon

20-25 %N2

15-20% He

Rest H2, 02



Neon

Separation

Pure

Neon

1st enrichment

Separation

Rare Gas Production

THE LINDE GROUP

Krypton & Xenon Process Flow

LOX incl.

2000 ppm

Kr/Xe

Large Air Separation Unit (ASU) with rare gases column

Air intake > 150,000 m^3/h or oxygen capacity > 30,000 m3/h

Kr/Xe Enrichment 99%

Kr/Xe Separation

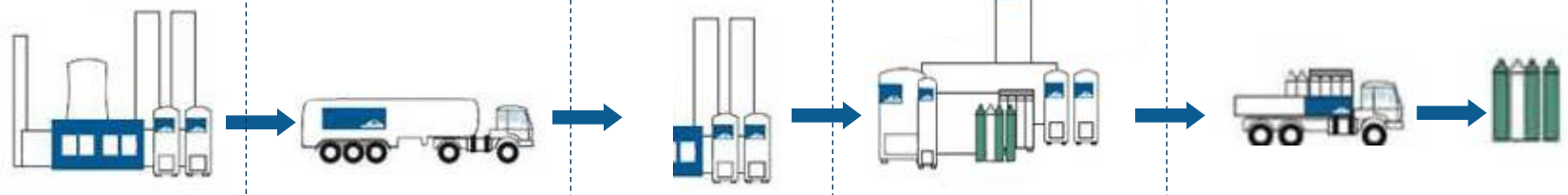
Pure Kr / Xe

1st enrichment → 2nd enrichment → Separation

Rare Gas Production

THE LINDE GROUP

From the source to customer



Tonnage ASU

Transport of Crude gas

Enrichment & Separation

Specialty Gases Production

Cylinder transport

Custome r

TONNAGE **BULK** **RARE GASES** **SPECIALTY GASES** **DISTRIBUTION**

Rare Gas Recovery

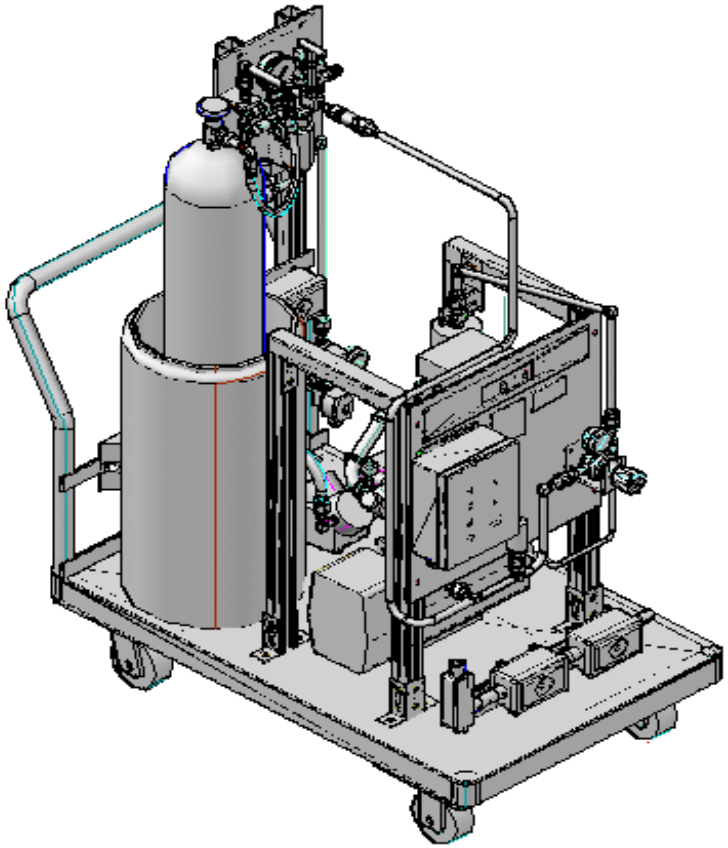
There are a number of applications where Rare Gases (Xe, Kr, Ne) are used, but not consumed. The used gas can be captured and purified.

Recovered Rare Gases can be repurified to meet the same purity specifications.

Unlike adding production capacity, recovery can often be done quickly and relatively inexpensively.

Rare Gas Recovery

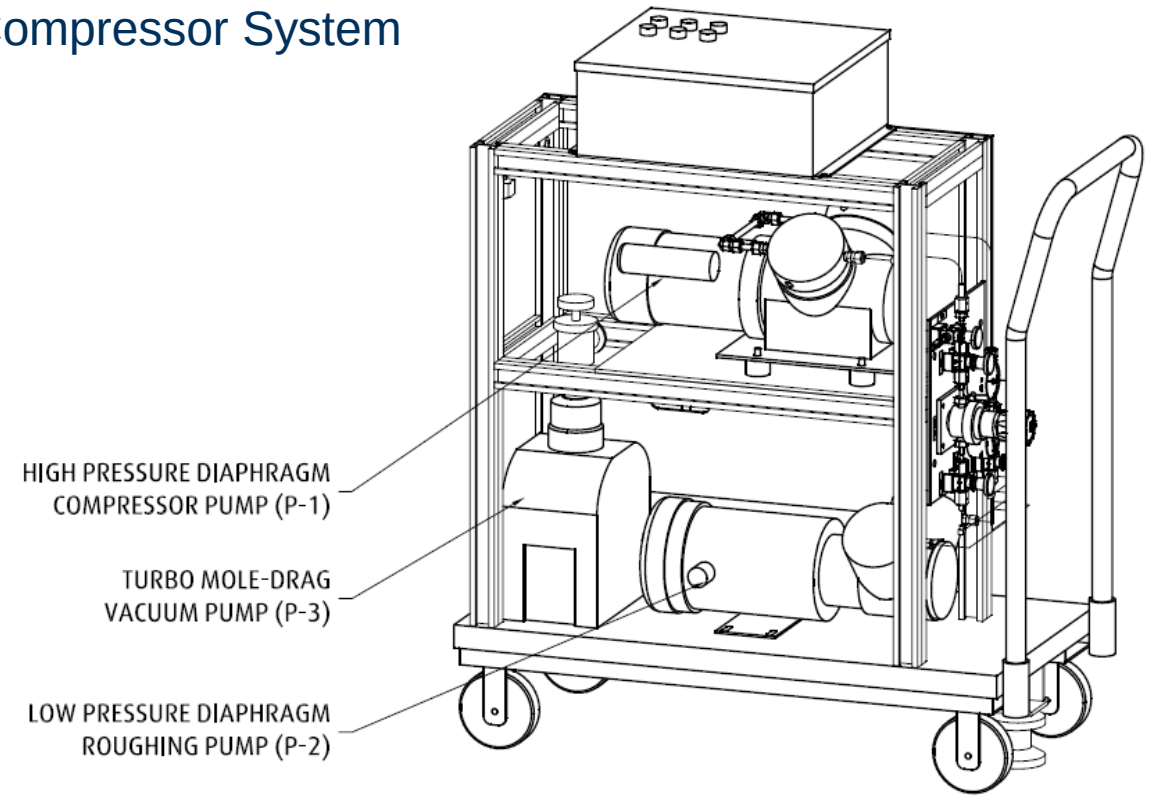
Cryogenic Recovery



Rare Gas Recovery

THE LINDE GROUP

Compressor System



Rare Gas Recovery

THE LINDE GROUP

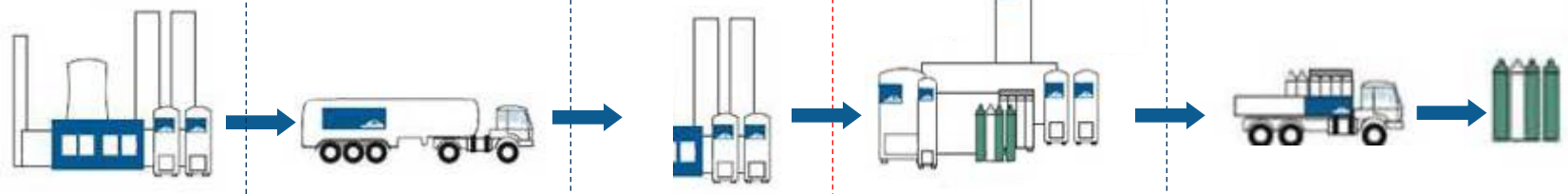
Rare Gas Purification

The Rare Gases can be purified using the same systems that produce the purified gases from air.

Rare Gas Purification

THE LINDE GROUP

From the source to customer



Tonnage ASU

Transport of Crude gas

Enrichment & Separation

Specialty Gases Production

Cylinder transport

Custome r

Collected Rare Gases

TONNAGE **BULK** **RARE GASES** **SPECIALTY GASES** **DISTRIBUTION**

Summary

There are a number of applications where Rare Gases (Xe, Kr, Ne) are used, but not consumed.

In these applications the used gases can be collected and purified.

Rare gas recovery offers the potential for reduced costs and increased security of supply.

Thank you!

Questions?

LeadIng.

THE LINDE GROUP